



Corona Camera Inspection

Abstract:

There are many on-line and off-line methods of testing and inspecting Turbine Generator Stator (TGS) windings. All involve some degree of investment in equipment and hardware - at times quite expensive. However, a visual inspection of a generator can speak volumes to you, with regard to its operating condition. Dusting is one of the characteristics that a generator may exhibit at some point in its lifespan. Caught early, corrections to this issue can add literally years to the life of you generator. It is important that we all learn to read the tale-tell signs.

Dusting is created by one of two different phenomena. Under the right circumstances, both can be working in consort with one and another within the same area. Mechanical dusting is generated when two components fret against one another. This activity leaves a deposit of fine particles. Left unchecked, this phenomenon could potentially abrade through critical insulated components leading to dielectric failure. Corona dusting can be generated within the stator slots, slot exits, end windings, and connections. Slot discharges occur when the coils become loose, causing the winding capacitive charging current to be dissipated to ground through concentrated contact points. This in turn generates localized areas that appear to glow, spark, and eventually burn. Left to continue, this phenomena will eventually compromise the ground wall insulation system and result in a winding failure to ground. Stress gradient materials, in particular those comprised of paints or varnishes, are susceptible to deterioration due to high thermal factors. Eventually, the interface between the stress gradient and the semi-conductive components is breached. This gap allows for the inception of discharging. Although this discharge activity can appear pronounced and wide spread, it is considered to be a rather

slow acting mode of deterioration. Corona discharges might also occur in stator slot and based on other visual symptoms, part of the slot should be unwedged to see extent of corona activity going on in the slot.



Mechanical dusting is generated when two components fret against one another (above left). Corona dusting can be generated within the stator slots, slot exits, end windings, and connections (above right).

Our experience over the years has demonstrated that the UV camera is an important tool for simulation and visualization of corona activity while generator stator winding is energized with AC Voltage. This gives significant inputs in overall reliability assessment of stator winding and in determining the solution required to avoid/minimize the corona activity.

Introduction:

Monitoring of corona activity assists in identification of insulation problems and areas of high electrical stress and is one of the key factors in assessing overall reliability assessment of condition of generator stator windings. Corona is a phenomenon which arises from ionization of the air due to high electric field. These fields appear either as a result of poor electric field distribution due to choice of incorrect parameters during design and or environmental contamination during operation and or due to deterioration in Corona sup-



Corona Camera Inspection (continued)

-pression system of the winding coils/ bars. Apart from visual tell tale signs of corona dusting, we at WGGs make use of Corona Camera to provide us an assessment of corona activity taking place in a generator during the maintenance inspection and testing called Generator Assessment Programs (GAP's) at WGGs. These corona discharges are external to the basic insulation and are on the surface of the coil due to loose windings, semi-conducting / stress grading deterioration, contamination, and inadequate spacing, among others. Each of these issues are discussed later in the paper.

A Word About the Corona Camera:

The Corona Camera provides video image of corona activity in the form of images of light waves generated by the corona during the day light conditions because of the camera's ultra violet imaging system. As the video provides moving image, it is possible to characterize the type of corona. As this video image of corona is superimposed on the test object, it allows for the determination of the position of the corona and its possible cause, depending on the location of this spot in the winding and other related issues. At the same time it provides a quantification of corona activity, which permits in risk assessment, pre-failure partial fixes and planned replacements to prevent failures in service.

Corona Monitoring in Generators and Related Causes:

Generally we look for a variable corona, changing its shape, direction, and size. This can be seen at slot exits and winding ties. At times it becomes necessary to have access to bar / coil side in the slot for corona monitoring and this is done through removal of a few wedges. We also look for a kind of spark gap corona in between bars / coils in the end winding, in between circuit rings, at cross over points and this might be due to initial design / winding installation issues or appearing due to significant contamination on the end windings.

Looseness of Windings in slot:

It is not unusual for windings to become loose in the slot due to the combined effect of electro dynamic and thermal cycling forces due to wear out of high spots on coil side, side pack, wedge etc over the years during operation. There can also be other issues like shrinking of some insulation res-

ins on post cure and shrinking of some of the wedging and packing materials allowing the coils to become loose. This is especially so for conventional wedging system. In windings fitted with top ripple springs and or side ripple springs, such chances of looseness are considerably minimized. While in the presence of oil, wedges, side packing and top ripple springs will tend to soften faster because of the lubricating medium.



Subjected to oil (above left), wedges, side packing, and top ripple springs softened and loosen. In an oil-saturated environment, loose wedges will produce a greasy-type byproduct (above, right).

If the coils are loose, the looseness will quickly allow the laminated rough stator core surface to damage the surface coatings on the coil. Damaged coil surfaces create discontinuities on the surface allowing voltage stresses to build up across these isolated locations, or, between these and the stator iron. If the voltage stress exceeds the electrical breakdown point of the air / gas medium, a discharge will occur. Eventually, a ladder effect develops where the groundwall is thinner at the point of contact with the core, but maintains normal thickness at the core air vents. Slot discharges accelerate the decomposition of the organic epoxy or polyester resin binders and the coils tend to decrease in size and may become further loose. Thus, machines with slight damage to the coil surfaces can still provide many years of reliable operation provided movement is stopped by a rewedge. Once damaged, it is difficult to restore the semi-conducting surfaces - so prevention is paramount.

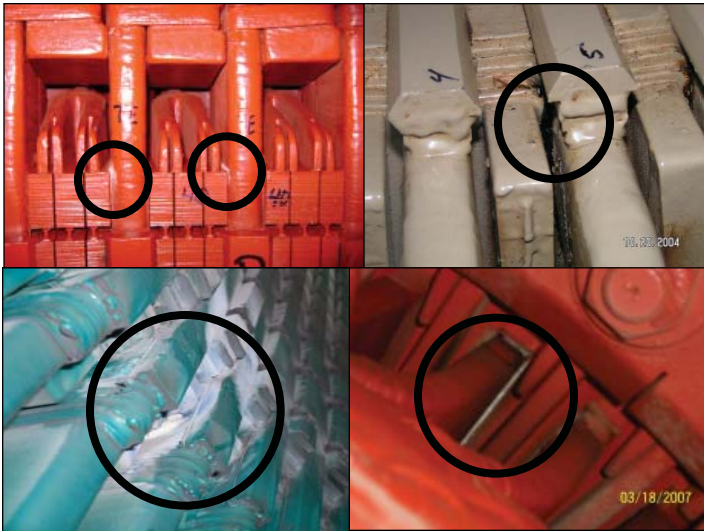


Ladder effect due to loose stator windings (above, left). The effects of mechanical and corona damage to side ripple springs (above, right).



Corona Camera Inspection (continued)

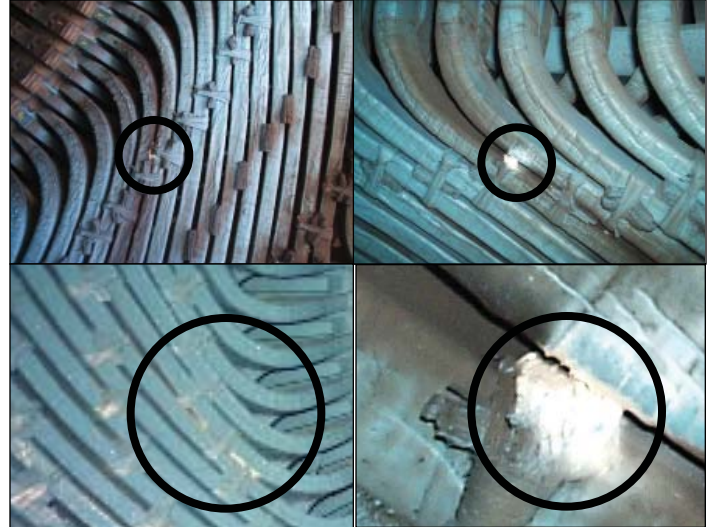
Windings with severely damaged surface coatings may require replacement because of the high production of ozone and accelerated erosion of ground wall insulation by slot discharges. The absolute time between detection of looseness and failure is kind of unpredictable, but it can be fairly short in hard thermoset windings, especially in those with a high electric stress across the groundwall. Air-cooled machines are much more prone to slot discharges. Based on visual observations on the winding and results of wedge tightness test, it may be determined if monitoring corona activity in a sample slot is required as input to the reliability assessment program in estimating condition of corona suppression system. Following pictures illustrate some typical cases of corona activity caused by looseness of winding:



Inadequate Spacing:

If there are two adjacent components from different phases with insufficient spacing between them, it is highly likely that corona activity will occur between the two. These components could be connection rings, end arms of different phases, etc. In air-cooled machines this corona activity leaves a white powder residue. This is a typical case of spark gap corona monitoring. Once a void is created on the surface of insulation, a potential difference builds across it and the discharges occurring across the void slowly erode the groundwall. Eventually a time may come when failure may take place. The closer the coils or components, shorter is the time to failure. The combination of inadequate spacing and a polluted operating environment can provide an ideal condition for corona discharge on the surface. Typically, nothing much can be done other than cleaning corona dusting and applying epoxy coating to minimize damage between two maintenance intervals. A permanent fix is redesign and rewind the genera-

tor. Following pictures illustrate some typical cases of corona activity caused by inadequate spacing:



Winding Contamination:

Any kind of conductive contamination from moisture or oil mixed with dust/dirt affects a machine as electrical tracking develops across the blocking or along the end arms. The electrical tracking occurs since a conductive path between two adjacent coils of different potential is created, and often from different phases. This is essentially a case of spark gap corona activity which occurs not because of mere design issues on the winding but winding contamination issues. This means once the contamination is removed, this corona activity will cease. As a result of the tracking, the groundwall insulation on the surface suffers deterioration. Left uncorrected, permanent phase-to-phase or phase-to-ground deterioration may occur and eventual failure of the groundwall is possible. Moisture condensation can take place both if machine has been sitting idle or it is operating in a high humidity inside the generator casing on account of moisture ingress from cooling system and or water contaminated oil system. The situation is remedied again by cleaning corona dusting and applying epoxy coating to minimize damage between two maintenance intervals and fixing moisture /oil contamination issues. Following pictures illustrate some typical cases of corona activity caused by contamination:

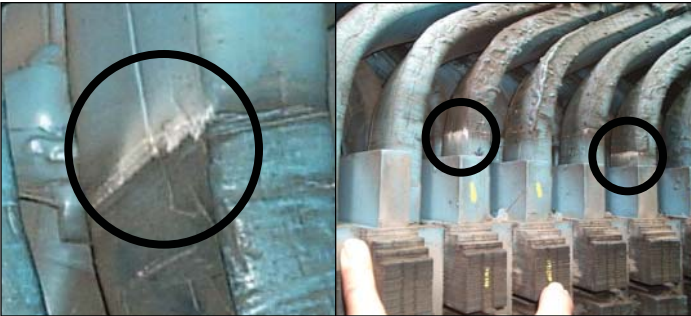




Corona Camera Inspection (continued)

Voltage Stress Interface:

For adequate control of the voltage stress of a winding, the interface between the semi-conductive coating/tape and stress grading coating/tape materials must be effective (Figure) Due to high electric stresses, temperatures and environmental contamination, this interface may deteriorate over time especially with paints for voltage stress control. As a result of this deterioration, the stress grading coating loses ground contact, floats to a higher-voltage and sparks across the interface to ground. In air-cooled machines, this leaves white-band of residue at the slot exits. This corona dusting is readily seen while inspecting generators. Insulation damage from this type of deterioration is a slow process but given that this location is close to the slot exit, it is most susceptible to a ground fault on the generator left undetected and corrected. This corona activity is a kind of variable corona and spark gap corona usually seen at slot exit. Following pictures illustrate some typical cases of corona activity caused by deterioration of voltage stress interface:



Corona Camera Operation:

In order to perform a Corona Camera examination, the generator or electric motor must be dismantled to such a stage as to expose the stator end winding. At a minimum (assuming a horizontal machine) this would require the removal of the upper-outer end shield, and the upper and lower-inner end shields. Next, the stator windings must be energized with an AC power source. The power source must be substantial enough to energize each individual phase to full line-to-ground potential. For a winding name plated at 13,800 VAC, this would equate to approximately 8,000 VAC. Each individual phase of the windings should be inspected individually, with the



other two phases and all stator slot RTD's grounded. The Operator, or the Operator's assistant should have a marker attached to the end of an insulated stick. This apparatus is utilized in order to locate any/all points of concern with respect to corona activity. The Corona Camera itself should be connected to a video recorder. In this manner, the entire inspection is captured on tape. It is our recommendation a Corona Camera inspection be performed as a part of the initial or in-process examination of a winding, as well as part of the final acceptance process. A comparative analysis can be performed in order to verify that any/all corona activity of concern has been extinguished.

Conclusion:

Routine inspection and testing of generators and electric motors is critical to assessing their condition and life expectancy. The more comprehensive the assessment, the more accurate the repair and rehabilitation procedures can be defined and implemented. With respect to high voltage windings, and their susceptibility to coronal damage, the inclusion of Corona Camera inspections into any assessment is a significant advancement in diagnostic services. The Corona Camera inspection pinpoints and video-documents very specifically the locations of corona activity.



Unlike the standard "Lights-out" examination, where the energized windings must be covered in order to block out all external light, the Corona Camera inspection is performed under normal lighting conditions. As such, the Corona Camera inspection is significantly safer to the operators and observers. No more fumbling around in the dark, waiting for one's eyes to adjust, while standing next to an energized winding.

For more information on Corona Camera inspection of generator and electric motor stator windings, contact Paul Heikinen or Devinder Singh at Wood Group Generator Services.